腦波訊號分析與神經工程

梁　勝　富
成功大學 資訊工程系/資工所/醫資所
sfliang@mail.ncku.edu.tw
Lab:神經運算與腦機介面實驗室
http://ncbci.csie.ncku.edu.tw/
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Neuroengineering

- Neuroengineering encompasses researches such as
  - Brain–computer interfaces to control robots or other computerized devices that can assist individuals who have paralytic injuries (Pfurtscheller, IEEE NSRE 06; Isaacs IEEE NSRE 00; Donoghue, J Physiol, 07)
  - Electrical stimulation of paralyzed limbs (Peckham, Annu Rev BME 07)
  - Visual/Auditory prostheses that translate digital pictures from cameras/sounds from microphones into signals that can be interpreted by the brain. (Brelen, J Neurosurg 06; Normann, Nat Clin Pract Neurol 07)
  - Engineering technology to investigate and treat neurological diseases (Kossoff, Epilepsia 04).

Neuroengineering


資訊科技與
神經工程

(科學發展　2011年5月，461期)

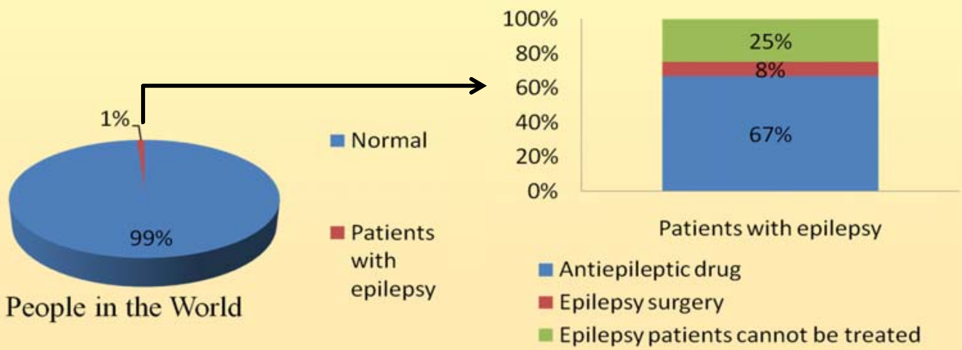
「神經工程的特色就是，利用工程技術所開發的系統或裝置，能與神經直接連結互動，直接接收神經訊號，或將訊號傳遞給神經。」

「腦機介面是利用腦部訊號，讓使用者可以直接與外界溝通。這項技術的基礎在於，當大腦在進行某一項特定活動的時候，會產生特定的腦波變化，因此透過監測與辨認此特定的腦波變化，來達到利用腦波進行與外界溝通及裝置控制的目的。」

「應用於癲癇抑制的反應式顱內電刺激，其運作方式乃持續監測腦波訊號，判斷是否有癲癇發作，當偵測到癲癇發作時，立即啟動電刺激器，立即給予電刺激，來抑制異大腦異常放電的發生。當腦波恢復正常狀態，則關閉電刺激器。」

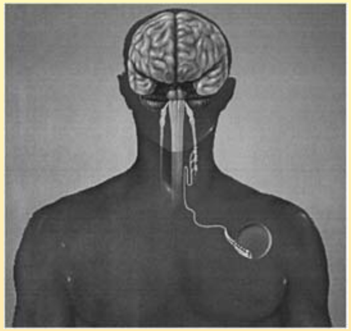
Seizure Control by DBS

- The worldwide prevalence of epilepsy is approximately 1%, and 25% of epilepsy patients cannot be treated sufficiently by any available therapy.



Seizure Control by DBS

- **Alternative techniques, such as vagus nerve stimulation or deep brain stimulation, have been proposed.**



VGS

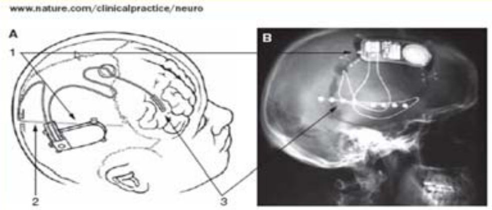


Figure 3 The NeuroPace Responsive Neurostimulator (RNS®) System (Mountain View, CA). (A) A schematic drawing and (B) a skull X-ray of the RNS® after implantation. The implantable device (1) records, processes and transmits electroencephalographic signals, in addition to generating the electrical stimuli. The implantable depth (2) and strip (3) electrodes monitor brain signals and deliver electrical stimulation to stop seizures. Panel A © NeuroPace, Inc., Mountain View, CA, USA. Permission for panel B obtained from Nursing Spectrum Nurse Wire © 2004.

DBS

Current Solutions

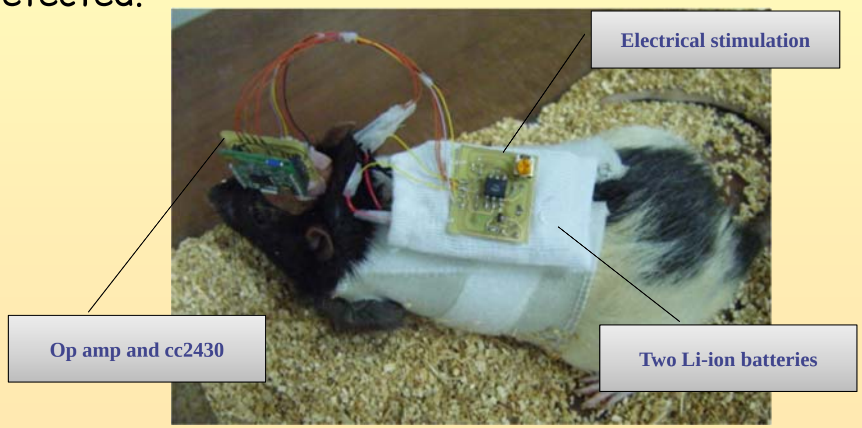
Company	Cyberonics, Inc.	Medtronic, Inc.	NeuroPace, Inc.
Company's Patent (related epilepsy)	24 Patents (1989~2006)	200 Patents (1991~2009)	48 Patents (1997~2009)
Product	(VNS Therapy®) System, (NCP) NeuroCybernetic Prosthesis System	the Intercept™ Epilepsy Control System	RNS® System
Treatment by Nerve Stimulation	Vagus Nerve Stimulation (VNS)	Deep Brain Stimulation (DBS)	Deep Brain Stimulation (DBS)
Main Claim	Continuous electrical stimulation of vagus nerve	Detection seizures and electrical stimulation of the internal globus pallidus (GPi) or the subthalamic nucleus (STN)	Detection seizures and electrical stimulation of STN

Closed-Loop DBS

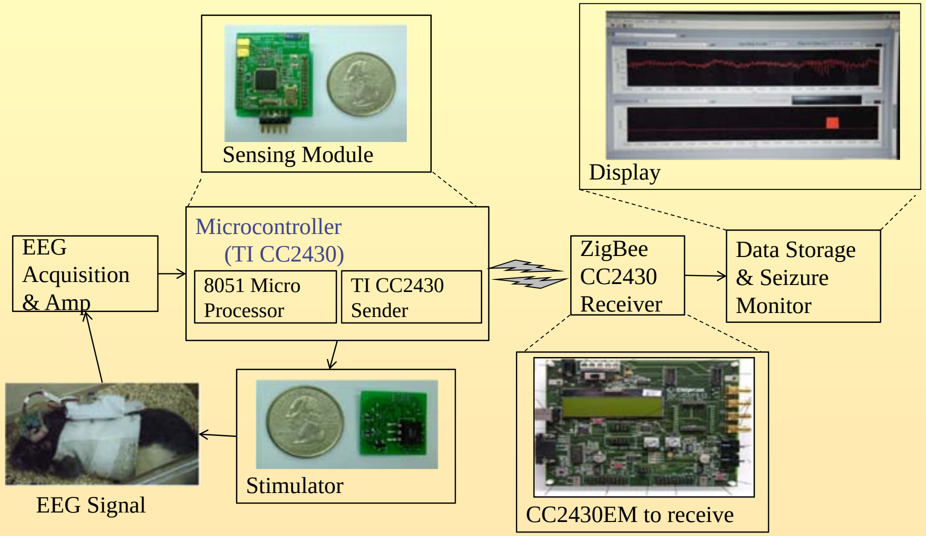
- Open-loop intermittent stimulation may tend to decrease in efficacy over time due to neuron acclimation.
- A closed-loop device with real-time seizure detection can deliver less-frequent-but hopefully more effective intervention than open-loop devices.
- It relies on a robust and on-line abnormal signal detection method for closed-loop DBS.

Closed-loop Seizure Controller

- It can perform on-line EEG monitoring and provide the electrical stimulation when a seizure event is detected.



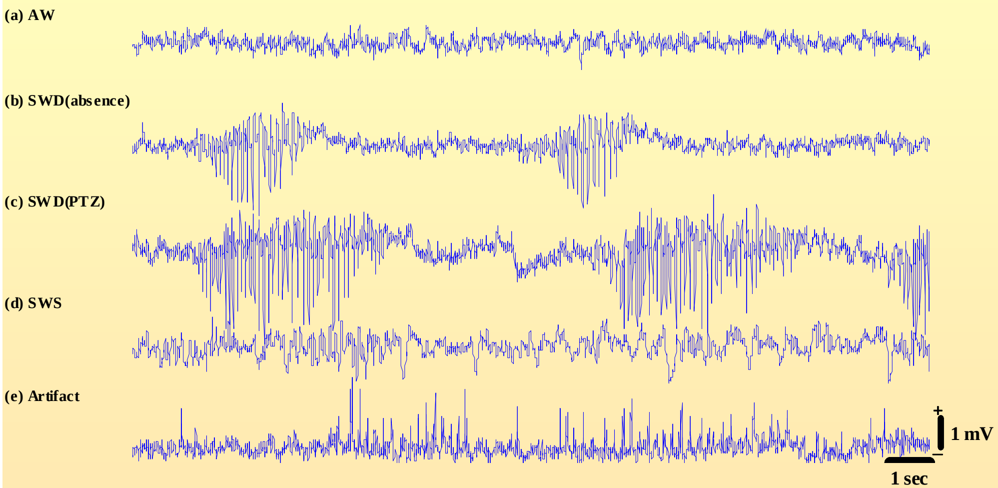
Block Diagrams of the System



Animals and Electrodes

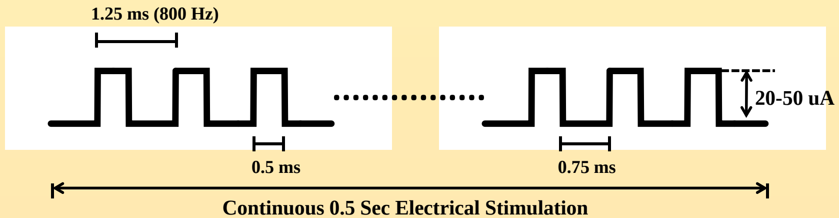
- Two epileptic rat models were developed.
  - Long-Evans rats with spontaneous non-convulsive spike and wave discharges (SWDs).
  - Pentylenetetrazol (PTZ)-induced seizures.
- Recording-screw electrodes were bilaterally implanted over the area of the frontal barrel cortex.
- Stimulation-a 4-microwire bundle, was used to stimulate the right-side zona incerta (ZI).

EEG Recordings

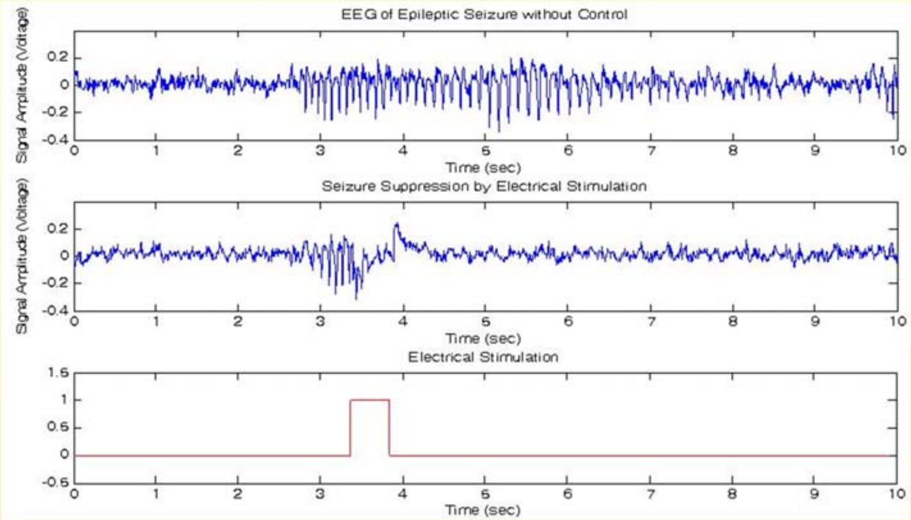


Stimulation

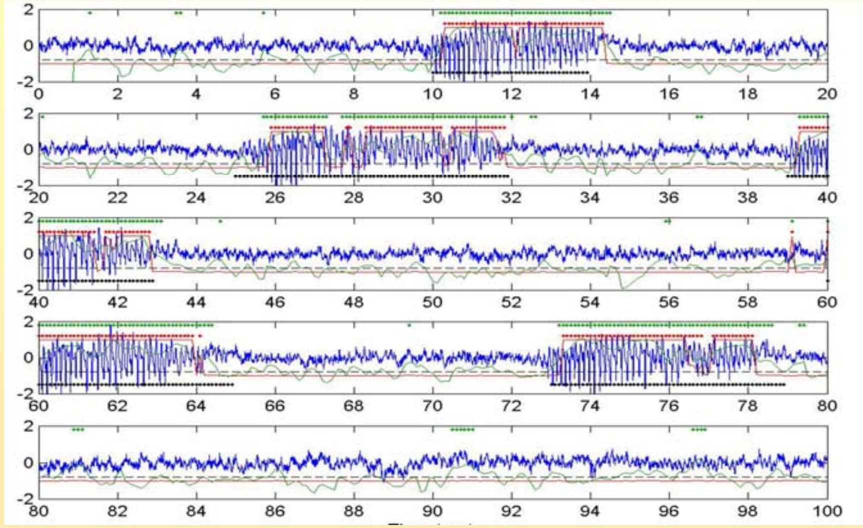
- Continuous electrical stimulation
  - Zona Incerta (ZI) stimulation
  - Train duration: 500 ms
  - Frequency: 800 Hz
  - Duty cycle: 40 % (0.5 ms)
  - Constant current: 20-50 uA



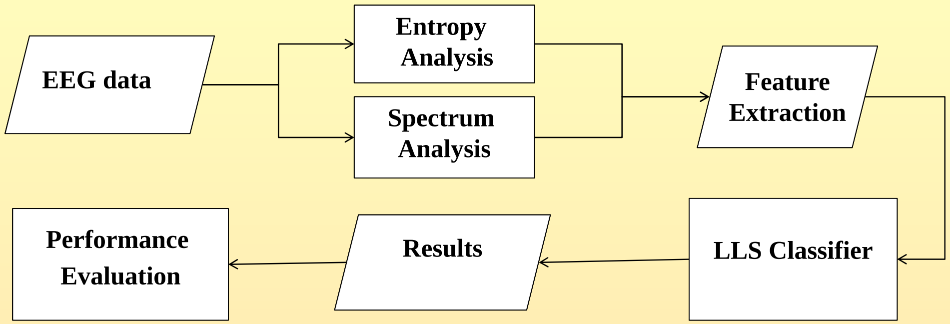
Electrical Stimulation



On-line Seizure Detection



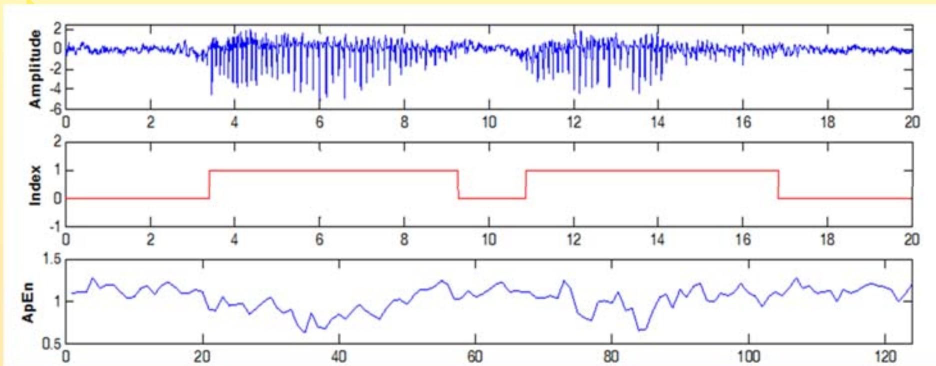
Seizure Detection



TI CC 2430

Approximate Entropy (ApEn)

- Approximate entropy (ApEn) is a measure that quantifies the regularity or predictability of a time series (Pincus, 1994).
- It counts the similarity of a vector and it's shifting version.



Approximate Entropy (ApEn)

- Srinivasan et al. (2007) successfully combined ApEn analysis with neural networks to discriminate between normal and ictal EEG signals, and the overall accuracy was as high as 100%.

Let the N-point time sequence of data equally spaced in time be $[u(1), u(2), \cdots, u(N)]$, first, form a sequence of vectors $x(1), x(2), \ldots, x(N\text{-}m\text{+}1)$ in $\mathbf{R}^m$,

$$x(i) = [u(i), u(i+1), \cdots, u(i+m-1)] \text{ for } 1 \le i \le (N-m+1), \quad (1)$$

where m is the length of the compared runs. Next, compare each element of each two vectors. Define the vector comparison distance which is the maximum difference of the relative elements in two sequences $x(i)$ and $x(j)$ as

$$d[x(i), x(j)] = \max[|u(i+k) - u(j+k)|], \text{ for } k = 0, 1, \cdots, (m-1). \quad (2)$$

For each i, $1 \le i \le N-m+1$, we define

$$C_i^m(r) = \frac{\sum_{j=1}^{N-m+1} \omega_j}{N-m+1}, \quad (3)$$

where

$$\omega_j = \begin{cases} 1, & \text{if } d[x(i), x(j)] \le r, \\ 0, & \text{else}, \end{cases} \quad (4)$$

where r is the tolerance of d. Finally, define $\Phi^m(r)$ as follows

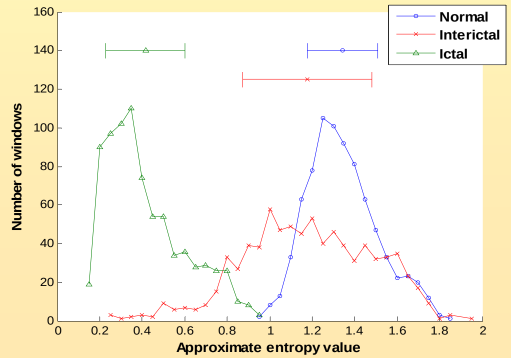
$$\Phi^m(r) = \frac{\sum_{i=1}^{N-m+1} \ln C_i^m(r)}{(N-m+1)}. \quad (5)$$

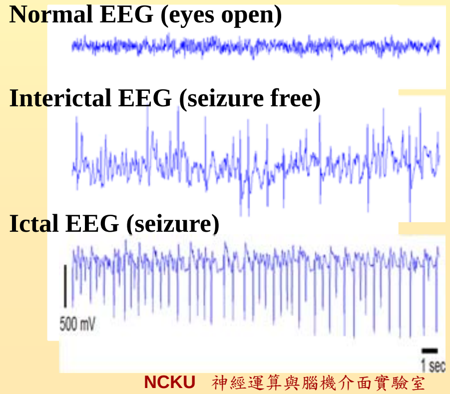
The approximate entropy, ApEn, can be calculated by

$$\text{ApEn}(m, r, N) = \Phi^m(r) - \Phi^{m+1}(r). \quad (6)$$

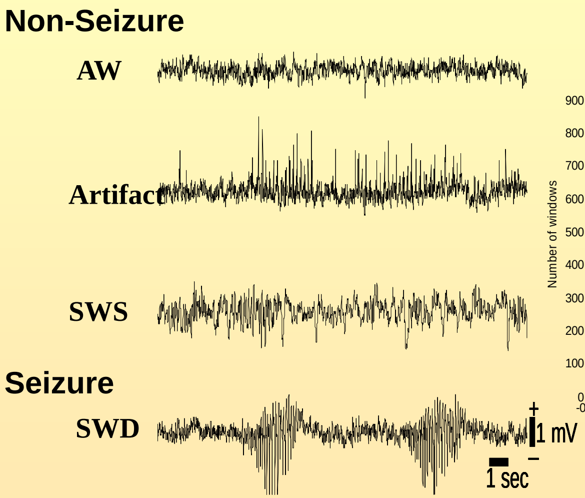
Approximate Entropy (ApEn)

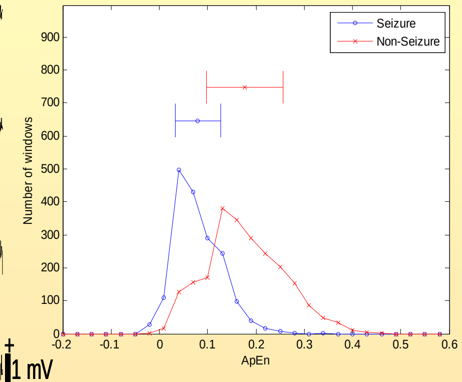
- ApEn is a useful feature to discriminate normal and siezure EEGs.
- However, ApEn values of the interictal EEGs overlapped with those of the normal and the ictal EEGs.





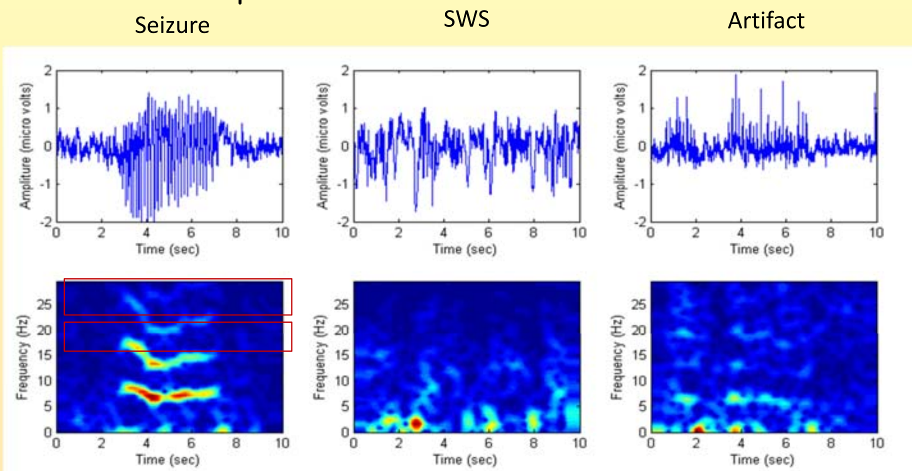
Continuous EEG Recordings





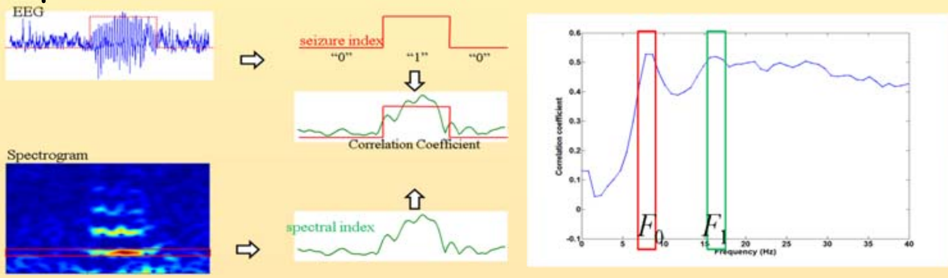
Time-Frequency Analysis

- The EEG power spectrum was utilized as the complementary feature of ApEn.



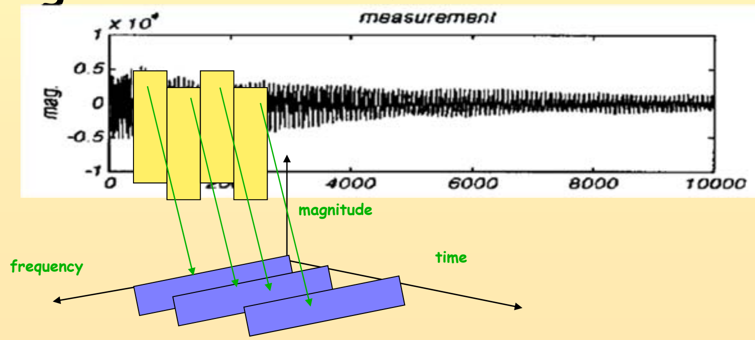
Spectral Features-STFT

- Short-term Fourier Transform was used for spectral analysis.
- Frequency bands corresponding to the top two correlation coefficients were extracted as the spectral features.



STFT

- **Slicking the waveform into a number of short segments and performing the analysis on each of these segments by using Fourier transform.**

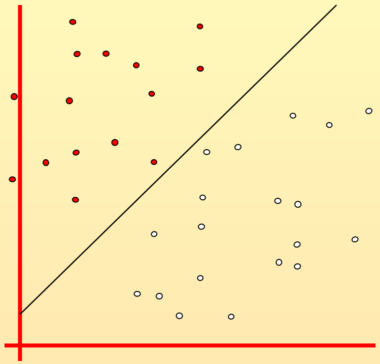


Classification-LLS

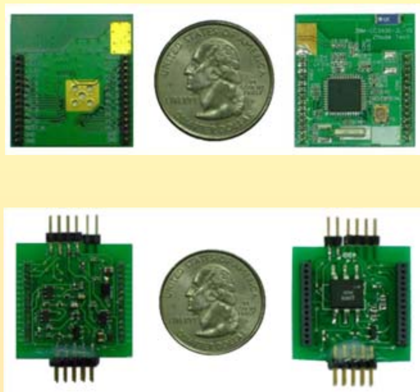
- One entropy value and the powers of two selected frequency bands were used for classification.
- A linear classifier called linear least squares (LLS) was utilized as the classifier.

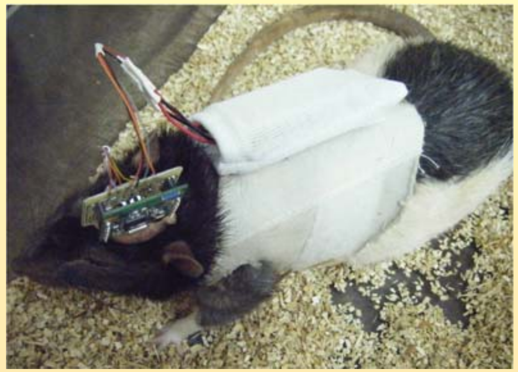
The i^{th} output of the LLS, y_i, is the linear combination of the i^{th} feature vector X_{ij} as

$$y_i = \sum_{j=1}^{n} X_{ij}\beta_j$$

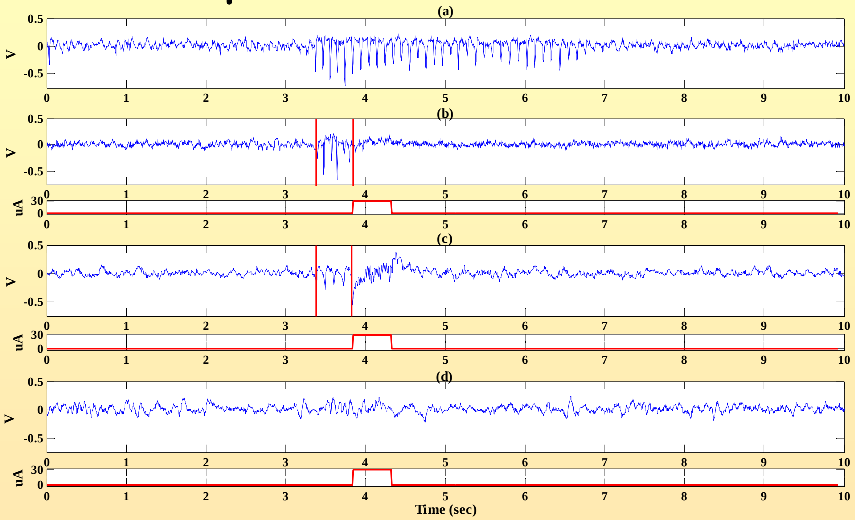


Closed-loop Seizure Controller



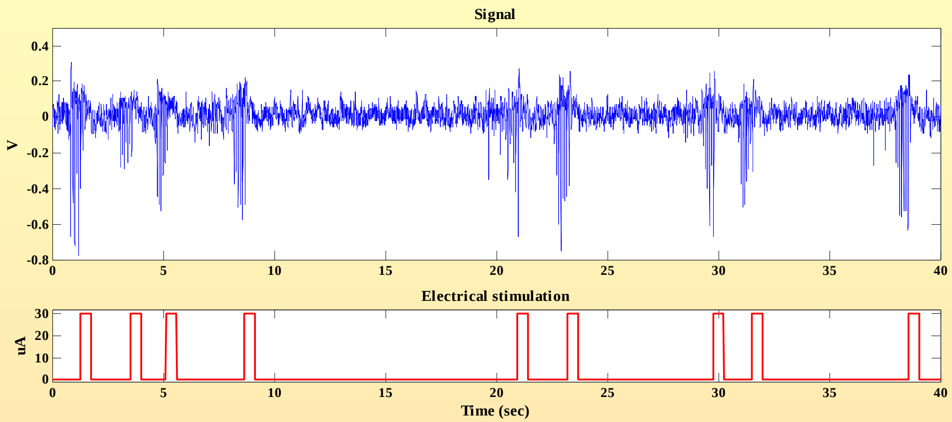


Experimental Results



(a) Spontaneous EEG containing an SWD without seizure controller, (b) EEG under a closed-loop seizure control (single absence seizure), (c) EEG under a closed-loop seizure control (single PTZ-induced seizure), (d) EEG with false stimulation of the closed-loop seizure control. Lower panels shown in (b)-(d) are electrical stimulation pulse.

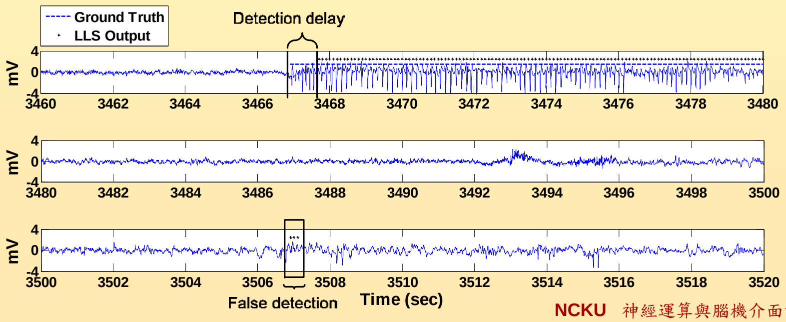
Experimental Results



EEG containing multiple absence seizure SWDs under a closed-loop seizure control

Performance Evaluation

- The performance of the seizure controller was evaluated by three indices:
  - accurate stimulation rate,
  - false stimulation rate,
  - detection delay time.



Performance Evaluation

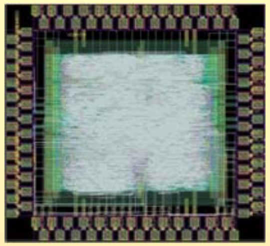
- Seizure detection rate is above 92%, the false stimulation rate is less than 2.5%, and the detection delay is less than 0.6s.

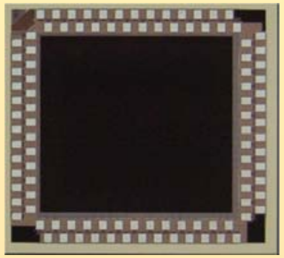
Subjects			SWD	Detected SWD	Accuracy	False stimulation	Detection delay (s)
#1	Light-on (2 hours)	Awake	349	343	97.7%	1	0.536
		Sleep	46	43		8	0.545
	Light-off (2 hours)	Awake	248	247	99.1%	0	0.491
		Sleep	100	98		9	0.567
#2	Light-on (2 hours)	Awake	250	230	92.0%	0	0.547
		Sleep	4	2		0	0.599
	Light-off (2 hours)	Awake	246	235	95.2%	4	0.540
		Sleep	26	24		2	0.556
#3	Light-on (2 hours)	Awake	644	627	97.3%	17	0.471
		Sleep	0	0	---	0	n/a
	Light-off (2 hours)	Awake	449	442	99.1%	8	0.485
		Sleep	0	0	---	0	n/a

#1,2: spontaneous SWD
#3: PTZ induced SWD

(IEEE TIM vol. 60, no.2, pp. 513-521, 2011)

Low-power IC





COMPARISON OF EPILEPTIC SEIZURE DETECTORS

	Enhanced 8051 microcontroller + signal conditioning board(10')	The low-power RISC (11')
Operating Frequency	32 MHz	13.6 MHz
Power Consumption of Analog Part	N/A	0.548 mW
Power Consumption of Digital Part	N/A	6.66 mW
Total Power Consumption	117.66 mW	7.21 mW
Energy per Seizure Event Determination	18.8 mJ	1.15 mJ
Battery Life (3.7V, 1100 mAh)	28 hours	18.9 weeks

(IEEE JETCAS 2011)

Sleep Problems

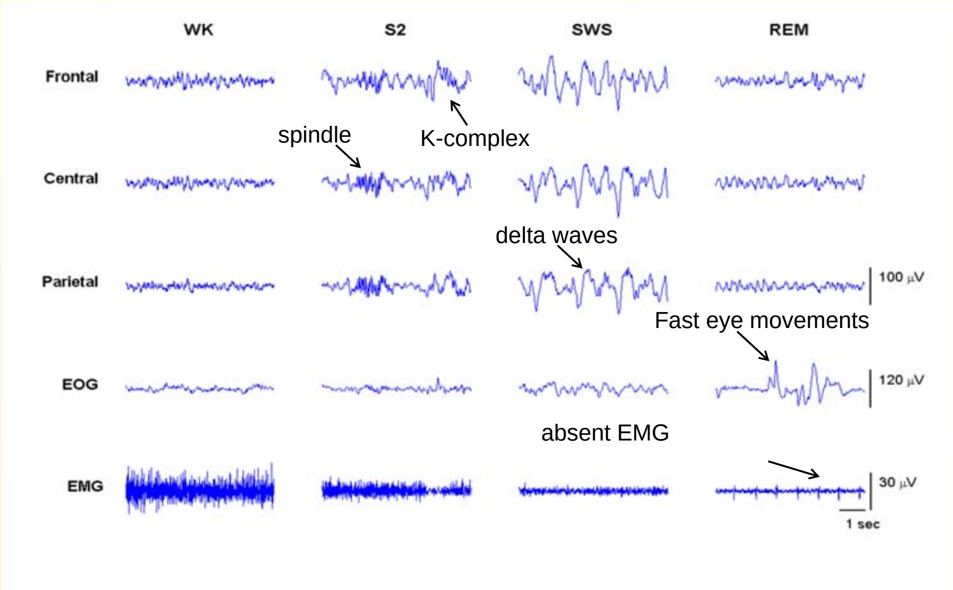
- Human beings spend approximately one third of their life in sleeping.
- The prevalence of insomnia symptoms is approximately 33% in the general population (Ohayon, 2002).
- Obstructive sleep apnea affects over 2% of adult women and 4% of adult men (Mahowald et al., 2005).

Sleep Recording and Scoring

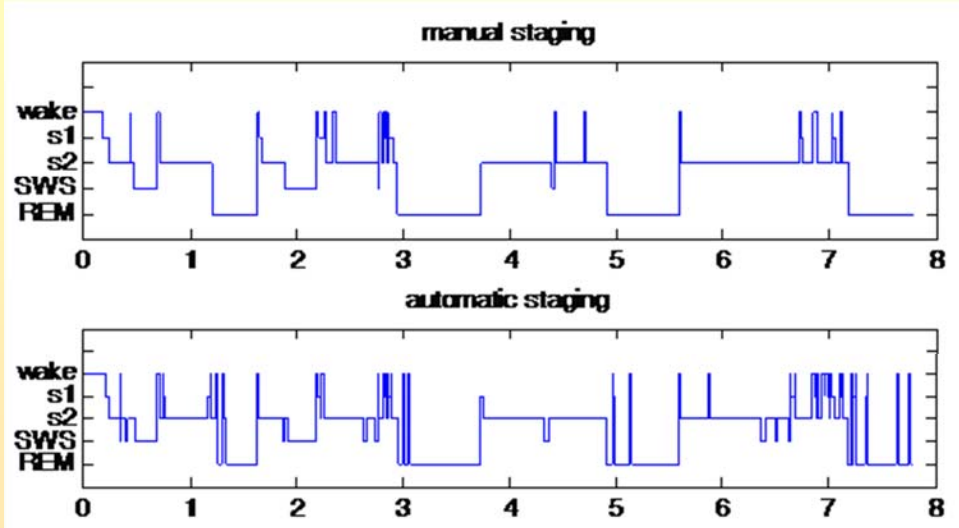
- PSG is used in hospitals and sleep centers.
- Sleeping in an unfamiliar environment such as a hospital may cause the first night effect.
- The PSG recordings are scored by a well-trained expert according to the Rechtschaffen & Kales (R&K) rules.
- Portable devices integrated with the automatic sleep scoring are desired for homecare.

Portable PSG for Homecare

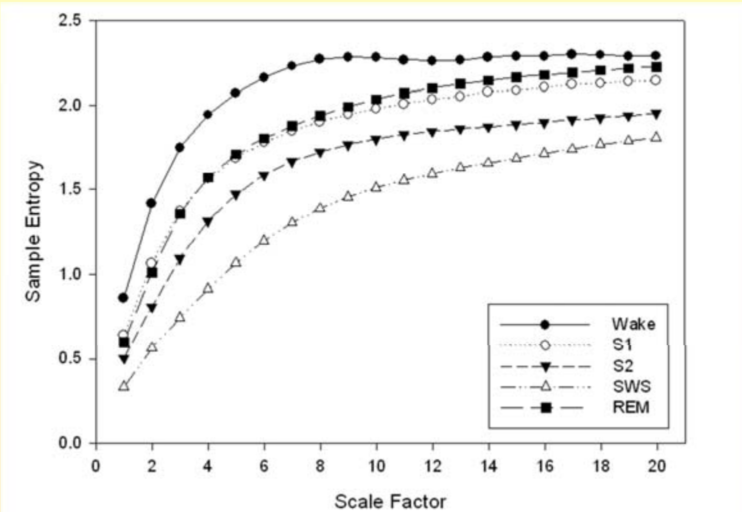
PSG Signals



Automatic Sleep Scoring System



Multiscale Entropy to Sleep EEG



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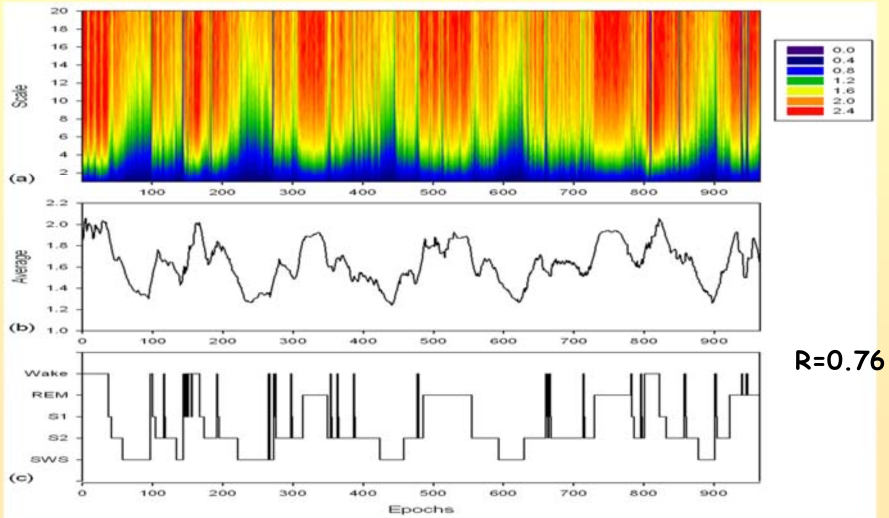
MSE and Sleep Staging

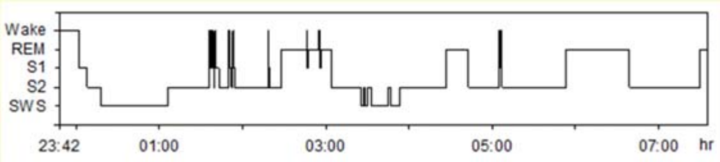


R=0.76

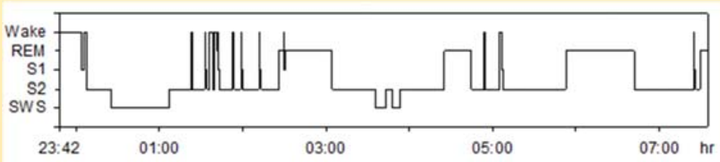
(Computer Methods and Programs in Biomedicine, vol. 104, pp. 382-396, 2011I)

MSE-based Sleep Staging

Manual Scoring



Scoring by computer



(IEEE BioCAS 2011)

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  - Profs. F.Z. Shaw, C.P. Young, D. Chang, A. Su and their lab members, NCKU
- Collaboration
  - Dr. C.T. Lin and BRC, NCTU
  - Drs. Peter Wu, J.C. Chiou and BSRC, NCTU
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- Collaboration
  - BSRC & BRC, NCTU

Any Questions ?